Geotechnical Engineering Report

TPWD – Water Supply Utility Upgrade
Randall County, Texas
February 19, 2017
Terracon Project No. A4165269

Prepared for:
Texas Parks and Wildlife Department (TPWD)
Austin, Texas

Prepared by:
Terracon Consultants, Inc.
Midland, Texas

Terracon

February 19, 2017

Texas Parks and Wildlife Departments (TPWD)
4200 Smith School Road,
Austin, Texas 78744-3291

Attn: Ms. Janie Ramirez, CTPM, CTCM
Contract Manager of Infrastructure Division
O: 512-389-4800
E: Janie.ramirez@tpwd.texas.gov

RE: Geotechnical Engineering Report
TPWD – Water Supply Utility Upgrade
NEQ of Palo Duro Drive and Sunday Canyon Road
Palo Duro Canyon State Park, Randall County, Texas
Terracon Project No. A4165269

Dear Ms. Ramirez:

Terracon Consultants, Inc. (Terracon) has completed the geotechnical engineering services for the referenced project. This study was performed in general accordance with our proposal, PA4165269, dated December 23, 2016 and TPWD purchase order, 491018, dated January 4, 2017. This report presents the findings of the subsurface exploration and provides geotechnical engineering recommendations concerning the design and construction of structure foundations and other site development elements for this project.

We appreciate the opportunity to be of service to you on this project. If you have any questions concerning this report, or if we may be of further service, please contact us.

Sincerely,
Terracon Consultants, Inc.
Texas Registration #3272

Alireza

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2/19

Alireza (Ali) Ahmadi, M.S.C.E., P.E.
Project Geotechnical Engineer

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Principal/ Department Manager

Enclosures
Copies Submitted: Addressee: (1) Electronic

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EXECUTIVE SUMMARY

A geotechnical exploration has been performed at an existing water supply utility for the purpose of its future expansion. The existing water supply utility was located in the northeast quadrant (NEQ) of the intersection of Palo Duro Drive and Sunday Canyon Road, inside Palo Duro Canyon State Park in Randall County, Texas. The future expansions are located to the east and south of the existing facility. Six (6) borings were planned to be advanced to a depth of 25 feet below existing ground surface (bgs) at the locations specified by the client. However, as a result of auger refusals, our borings were terminated at auger-refusal depths varying from 7 to 16 feet bgs. Based on the information obtained from our subsurface exploration, we believe the site can be developed for the proposed project. The following geotechnical considerations were identified:

- The project site was covered with dense mesquite, small trees and vegetation which need some clearing to make access roads for a regular size drilling rig to get to boring locations. Since clearing was not allowed for this site due to the nature of a state park, a small-size track-mounted drill rig was utilized for this project. We note due to limited power of this small size drill rig, the materials caused auger refusals could be dense soils rather than rocks. We observed some caliche materials on the site, so auger refusals on the site could be caused by caliches. The recommendations provided in this report are based on an assumption that dense soils or caliches exist at the boring-termination depths. If different type of subsurface materials are discovered during construction, Terracon should be notified immediately to re-evaluate our recommendations.

- Surficial soft soils with standard penetration resistances (N-values) of 3 to 6 blows per foot (bpf) were encountered in the upper about 2 feet of existing grades in borings B-1, B-3, B-5 and B-6. We expect these surficial soft soils will either be stripped and removed during initial site preparation or densified during proofrolling operations. Additionally, soft sandy silty clay and sandy lean clay materials with N-values of 5 and 6 bpf were encountered in borings B-1 (area of proposed 10,000-gallon Filter Backwash Recovery Tank) and B-6 (area of the west 80,000-gallon Raw water Storage Tank) at depths of about 2 to 3 feet bgs, respectively. Two options can be considered for this situation. Option 1 would be placing tank foundations on the existing soft soils with a low net allowable soil bearing capacity of 2,000 pounds per square foot (psf). With this option, total settlements of foundations could be up to 1-1/2 inches. If this magnitude of settlement is structurally acceptable, Option 1 will be the most cost-effective option for tank foundations. Option 2 would be undercutting 3 feet of on-site soft soils and then re-compacting the 3-foot materials to at least 95% of their Standard Proctor (ASTM D698) maximum dry densities. The re-compaction should be conducted lifts by lifts with each loose lift thickness of no more than 9 inches. With Option 2, a net allowable soil bearing capacity of 2,500 psf can be used, and total settlements for this option would be on the order of 1 inch. Detailed recommendations for Option 2 are provided in section **4.2.1 Site Preparation** of this report.

- Although no fat clay was encountered in our borings, the on-site clay soils have relatively high liquid limit (LL) and plasticity index (PI) values. As a result, the on-site soils are expected to experience a potential vertical rise (PVR) in a range of 1 to 1.5 inches with fluctuation in soil's moisture contents. If on-site clay soils are intended to be used for structural fill, the on-site soils should be mixed with sand on 1 to 1 ratio by volume before it can be re-used. The LL and PI of structural fill should be no greater than 30 and 15 respectively. So if on-site soils are mixed with sand to be re-used, Atterberg Limits tests should be conducted on the mixed material to determine its LL and PI values. Otherwise, structural fill material can be imported from a borrow source.

- Shallow foundations can be used to support proposed structures on the project site. Other than the tanks in the areas of borings B-1 and B-6, a new allowable bearing capacity of 3,000 psf can be used for design of shallow foundations. Shallow foundations should be embedded at least 2 feet below final grades. We note gross allowable bearing capacity equal to net allowable bearing capacity plus overburden pressure.

- Hard, cemented, calcareous materials, locally called "caliches", were encountered in all of our borings at depths ranging from 1.5 to 9.5 feet bgs. We note that these materials have strong resemblances to rock and should be treated as soft rock. We caution that site grading and shallow foundation excavations may need a heavy-duty excavator, dozer equipped with a ripper, hoe ram, rock saw or jack hammer, and rock trenching equipment. Blasting could be required in confined space conditions such as utility-trench excavations. For grading contractor's bidding purpose, we have given a definition of rock in various excavation conditions in section **4.3 Excavation Conditions** of this report.

- Groundwater was not encountered in any of our borings at the time of our field exploration. Although groundwater level should be expected to fluctuate with change of season, precipitation and drainage condition, and groundwater could be at a different level at time of construction, groundwater is not expected to affect construction of shallow foundations on this site.

- The 2012 International Building Code (IBC) (Section 1613) seismic site classification for this site is determined to be D. A preliminary fault review based on the available fault maps are presented in section **4.8 Fault Rupture Review** of this report.

This summary should be used in conjunction with the entire report for design purposes. It should be recognized that details were not included or fully developed in this section, and the report must be read in its entirety for a comprehensive understanding of the items contained herein. The section titled **GENERAL COMMENTS** should be read for an understanding of the report limitations.

GEOTECHNICAL ENGINEERING REPORT
TPWD – WATER SUPPLY UTILITY UPGRADE
AMARILLO, RANDALL COUNTY, TEXAS

Terracon Project No. A4165269
February 19, 2017

1.0 INTRODUCTION

The existing water supply utility is located in the NEQ of intersection of Palo Duro Drive and Sunday Canyon Road, inside Palo Duro Canyon State Park in Randall County, Texas. The future expansions are to be located to the east and south of the existing facility. Our scope of services included advancing six (6) borings, laboratory testing, field testing, and engineering analyses. The purpose of these services is to provide information and geotechnical engineering recommendations relative to:

- subsurface soil conditions
- groundwater conditions
- earthwork
- seismic considerations
- site preparation
- recommendations for shallow foundation
- lateral earth pressures

2.0 PROJECT INFORMATION

2.1 Project Description

Item	Description
Proposed construction (according to the site layout plan provided by client)	A water supply facility exists at the project site. The existing structures are located on the northwestern portion of site. Some new structures are proposed on the eastern and southern portions of the site. These new structures consist of: < A Package Plant < Two (2) Sludge Drying Beds. (2 to 3 feet deep) < Raw Water Pump Pads < Two Raw Water Storage Tanks (each with 80,000 gallon capacity) < 10,000-gallon Backwash Recovery Tank
Structural loads	The specific structural loads for the proposed structures are not provided by the client.
Finished grade elevation of structures	Within ± 2 feet of existing grade.
Cut and fill slopes	Permanent slopes assumed to be no steeper than 3H:1V (Horizontal to Vertical)

Item	Description
Below Ground Structures	Portions of the proposed raw water storage tanks and sludge drying beds could be below grade structures.

2.2 Site Location and Description

Item	Description
Location	The existing water supply utility is located in the NEQ of the intersection of Palo Duro Drive and Sunday Canyon Road, inside Palo Duro Canyon State Park in Randall County, Texas. The proposed future expansions are located to the east and south of the existing facility.
Existing improvements	An existing water supply utility
Current ground cover	Exposed soil, grasses, mesquites and shrubs
Existing topography	Ground surface of the project site slopes gently down to the southeast with an overall topographic relief of about 4 feet.

Should any of the above information or assumptions be inconsistent with the planned construction, please let us know so that we may make any necessary modifications to this report.

3.0 SUBSURFACE CONDITIONS

3.1 Typical Profile

Conditions encountered at the boring locations are indicated on the boring logs. Stratification boundaries on the boring logs represent the approximate locations of changes in soil types; in-situ, the transition between materials may be gradual. Details for the boring locations can be found on the boring logs in Appendix A of this report. Based on the results of the borings, subsurface conditions on the project site are generalized in the following table.

Description	Approximate Depth to Bottom of Stratum (feet)	Materials Encountered[1]	Density/Consistency[3]
Stratum I	1.5 t to 9.5	Sandy Lean Clay (CL), Lean Clay with Sand (CL) Sandy Silty Clay (CL-ML); dark gray, light gray, dark brown, light brown, tan	Soft to Hard
Stratum II	7[2] to 16[2]	Caliche: classified as Sandy Lean Clay (CL), Lean Clay with Sand (CL) Sandy Silty Clay (CL-ML); light gray and tan	Soft to Medium Stiff

<table>
<tr><th>Description</th><th>Approximate Depth to Bottom of Stratum (feet)</th><th>Materials Encountered[1]</th><th>Density/Consistency[3]</th></tr>
<tr><td>1</td><td colspan="3">The subsurface materials are not expected to experience substantial volumetric changes (shrink/swell) with fluctuations in moisture content.</td></tr>
<tr><td>2</td><td colspan="3">Our borings were terminated within this stratum at auger refusal depths varied from 7 to 16 feet bgs. We note that as a result of limitation in site clearing requested by the client, a small size rig was utilized at this project to minimize disturbance of native vegetation. We assume a deeper auger refusal depth could be achieved if a regular size rig such as CME55 was employed at this site.</td></tr>
<tr><td>3</td><td colspan="3">The N-value of the stratum I varied from 3 to 48 bpf which the majority of them were among 10 to 30 bpf. The N-values of Stratum II varied from 28 to more than 100 bpf.</td></tr>
</table>

3.2 Groundwater

The borings were advanced in the dry using continuous flight auger drilling techniques that allow short-term groundwater observations to be made while drilling. Groundwater was not observed during and at the completion of drilling.

These groundwater observations provide an indication of the groundwater conditions present at the time our borings were performed. Groundwater conditions may be different at the time of construction. Groundwater conditions may change because of seasonal variations in rainfall, runoff and other conditions not apparent at the time of drilling.

4.0 RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION

4.1 Geotechnical Considerations

The project site was covered with dense mesquite, small trees and vegetation which need some clearing to make access roads for a regular size drilling rig to get to boring locations. Since clearing was not allowed for this site due to the nature of a state park, a small-size track-mounted drill rig was utilized for this project. We note due to limited power of this small size drill rig, the materials caused auger refusals could be dense soils rather than rocks. We observed some caliche materials on the site, so auger refusals on the site could be caused by caliches. The recommendations provided in this report are based on an assumption that dense soils or caliches exist at the boring-termination depths. If different type of subsurface materials are discovered during construction, Terracon should be notified immediately to re-evaluate our recommendations.

Surficial soft soils with N-values of 3 to 6 bpf were encountered in the upper about 2 feet of existing grades in borings B-1, B-3, B-5 and B-6. We expect these surficial soft soils will either be stripped and removed during initial site preparation or densified during proofrolling operations. Additionally, soft sandy silty clay and sandy lean clay materials with N-values of 5 and 6 bpf were encountered in borings B-1 (area of proposed 10,000-gallon Filter Backwash Recovery Tank) and B-6 (area of the west 80,000-gallon Raw water Storage Tank) at depths of about 2 to 3 feet bgs, respectively. Two options can be considered for this situation. Option 1 would be placing tank foundations on the existing soft soils with a low net allowable soil bearing capacity of 2,000 pounds per square foot (psf). With this option, total settlements of foundations could be up to 1-1/2 inches. If this magnitude of settlement is structurally acceptable, Option 1 will be the most cost-effective option for tank foundations in the areas of borings B-1 and B-6. Option 2 would be undercutting 3 feet of on-site soft soils and then re-compacting the 3-foot materials to at least 95% of their Standard Proctor (ASTM D698) maximum dry densities. The re-compaction should be conducted lifts by lifts with each loose lift thickness of no more than 9 inches. With Option 2, a net allowable soil bearing capacity of 2,500 psf can be used, and total settlements for this option would be on the order of 1 inch.

Although no fat clay was encountered in our borings, the on-site clay soils have relatively high LL and PI values. As a result, the on-site soils are expected to experience a PVR in a range of 1 to 1.5 inches with fluctuation in soil’s moisture contents.

Subsurface conditions, as identified by the field and laboratory testing programs, have been reviewed and evaluated with respect to the proposed facility plans known to us at this time. Terracon should be retained at least during the earthwork phase of this project.

4.2 Earthwork

4.2.1 Site Preparation

Due to presence of soft soils in the areas of borings B-1 and B-6, undercutting of 3 feet of on-site soils and re-compacting the materials could be an option. With this option, the extent of the undercutting should be at least 5 feet wider in each direction than the footprint of the tank foundations in the areas of borings B-1 and B-6. The undercut materials should be temporarily stockpiled. If the material’s LL and PI values meet the requirements for structural fill, then the material can be placed back in the undercut space lift by lift with each loose lift no thicker than 9 inches. The backfilled material should be compacted to at least 95% of its Standard Proctor (ASTM D698) maximum dry density with moisture content controlled within ±2% of its optimum moisture content.

If the material’s LL and PI values do not meet the requirements for structural fill, then the material should be mixed with imported sand on 1:1 ratio by volume. The LL and PI values of the mixed material should be measured again to verify its suitability to be used for structural fill. If it meets the requirements, then the mixed material can be placed back and compacted in the same fashion as mentioned above.

Any topsoil or vegetation should be stripped and grubbed, and removed from the project site. Subsequently, the exposed subgrade should be proofrolled prior to the placement of any fill, foundation or pavement base materials. The proofrolling should be performed with a fully loaded, tandem-axle dump truck or other equipment providing an equivalent subgrade loading. A minimum gross weight of 20 tons is recommended for the proof-rolling equipment.

The proofrolling should consist of several overlapping passes in mutually perpendicular directions over a given area. Any soft or pumping areas should be excavated to firm ground. Excavated areas should be backfilled with properly placed and compacted fill as discussed in section **4.2.3 Compaction Requirements**.

4.2.2 Suitable Fill

If on-site clay soils are intended to be used for structural fill, the on-site soils should be mixed with sand on 1 to 1 ratio by volume before it can be re-used. The LL and PI of structural fill should be no greater than 30 and 15 respectively. So if on-site soils are mixed with sand to be re-used, Atterberg Limits tests should be conducted on the mixed material to determine its LL and PI values. Otherwise, structural fill material can be imported from a borrow source.

Structural fill materials need to meet the below requirements:

Fill Type [1]	USCS Classification	Acceptable Location for Placement
Imported Low Volume Change Material [2]	CL, SP, SW, SC LL< 30 & 7<PI<15	All locations and elevations (except upper 6 inches of final subgrade)
On-Site Soils	------	All areas outside structures footprint
Free-draining Material	GP, GW[3]	Upper 6 inches of final subgrade

1. Structural fill (a.k.a. engineered fill) should consist of approved materials that are free of organic matter, debris and gravels with maximum dimension of greater than 4 inches. A sample of each material type should be submitted to the geotechnical engineer's lab for evaluation before its use.
2. Low plasticity cohesive soil.
3. Similar to AASHTO coarse aggregate size No. 67, consistent with AASHTO designation M 43 and ASTM designation D 448.

4.2.3 Compaction Requirements

Recommendations for compaction are presented in the following table. We recommend that engineered fill be tested for moisture content and compaction during placement. Should the results of the in-place density tests indicate the specified moisture or compaction limits have not been met, the area represented by the test should be reworked and retested as required until the specified moisture and compaction requirements are achieved.

Item	Description
General subgrade preparation to receive fill	Surface scarified to a minimum depth of 6 inches, moisture conditioned and compacted
Lift thickness	9 inches or less loose lift thickness
Compaction	At least 95% maximum Standard Proctor dry density (ASTM D 698) in the range of ±2 percentage points of optimum moisture

4.2.4 Utilities

Care should be taken that utility trenches are properly backfilled. Backfilling should be accomplished with properly compacted engineered fill with loose lift thickness of generally 9 inches except for the first lift above the utility pipes that can be relaxed to 12 inches. Compaction should be accomplished with a hand-held compaction device inside utility trenches. Engineered fill should be compacted to at least 95% maximum standard Proctor dry density (ASTM D 698) in the range of ±2 percentage points of optimum moisture for the engineered fill.

4.2.5 Temporary Construction Slopes

For area which will have the excavations deeper than 4 feet below existing grade, the excavations must be protected in accordance with the applicable Federal, State, and local safety regulations and codes, and especially with the excavation standards of the Occupational Safety and Health Administration (OSHA).

If workmen are expected to work in trenches, trenches need to be sloped back or trench boxes or shoring need to be installed during construction. According to the OSHA soil classification, the on-site materials are generally classified as Type C soils. Temporary slopes of 1.5H:1V may be used.

Terracon’s recommendations for excavation support are intended for the Client’s use in planning the project, and in no way relieve the Contractor of its responsibility to construct, support, and maintain safe slopes. Under no circumstances should the following recommendations be interpreted to mean that Terracon is assuming responsibility for either construction site safety or the Contractor’s activities.

4.3 Excavation Considerations

Hard calcareous materials locally called “caliche” with varying degree of cementation were encountered in all borings. The caliche materials were encountered from depth of 1.5 feet to 16 feet bgs. Based on encountered subsurface materials, we caution site grading, shallow foundation installation and trench excavation may need heavy-duty excavator, dozer equipped with a ripper, hoe ram, rock saw or jack hammer, and rock trenching equipment. Blasting could be required to remove caliche in confine spaces such as utility-trench or strip footing excavation. We recommend the following definitions for rock should be included in earthwork section of the bid documents.

In Mass Excavation:	Any material occupying an original volume of more than 1 cubic yard which cannot be excavated with a single-toothed ripper drawn by a crawler tractor having a minimum draw bar pull rating of not less than 80,000 pounds usable pull (Caterpillar D-8 or larger).
In Trench Excavation:	Any material occupying an original volume of more than 1/2 cubic yard which cannot be excavated with a backhoe having a bucket

curling rate of not less than 40,000 pounds, using a rock bucket and rock teeth (a John Deere 790 or larger).

These descriptions are a guide to conditions generally encountered. Excavation techniques will vary based on the weathering of the materials, fracturing and jointing in the rock, and the overall stratigraphy of the feature. Actual field conditions usually display a gradual weathering progression with poorly defined and uneven boundaries between layers of different materials.

We recommend that soils that can be excavated with conventional grading equipment be removed first. Blasting should only be conducted where materials cannot be excavated by other trench excavation techniques.

4.4 Shallow Foundations

The proposed structures can be supported on conventional shallow foundations, such as spread footings, strip footing, mat foundations or slabs-on-grade. Shallow foundations should be embedded at least 2 feet below the final grades in undisturbed on-site subsurface materials or properly compacted structural fill. The following sections provide design recommendations for shallow foundations.

Due to presence to soft soils in the areas of borings B-1 and B-6, foundation options for the areas of borings B-1 and B-6 are listed in a separate table as shown below. So two tables are presented to provide recommendations for soft-soil and non-soft-soil areas.

4.4.1 Shallow Foundation Design Recommendations

Foundations in Areas of Borings B-1 and B-6		
Description	**Individual Footings**	**Strip Foundation**
Net allowable bearing capacity[1] n **On-site soft soils (Option 1)** n **compacted structural fill (Option 2)**	2,000 psf (Option 1) 2,500 psf (Option 2)	
Minimum dimensions	30 inches	24 inches
Minimum embedment below finished grade for frost protection[2]	24 inches	
Approximate total settlement[3]	1-1/2 inch (Option 1) 1 inch (Option 2)	
Approximate differential settlement[3]	¾ inch	
Allowable passive pressure[4]	125 psf triangular distribution	
Ultimate coefficient of sliding friction[4, 5]	0.31	
Modulus of subgrade reaction (K-value) for mat foundation design[6]	N/A	N/A

Foundations in Areas of Borings B-1 and B-6		
Description	**Individual Footings**	**Strip Foundation**

[1] The recommended net allowable bearing capacity is the pressure in excess of the minimum surrounding overburden pressure at the footing base elevation. Assumes any unsuitable fill or soft soils, if encountered, will be undercut and replaced with engineered fill.

[2] For frost protection consideration, an embedment depth of 12 to 18 inches could be used. However we recommend a 24-inch embedment for frost protection to reduce the effects of seasonal moisture variations in the subgrade soils. This value is intended for use in the design of perimeter footing and footings beneath unheated areas.

[3] The foundation settlement will depend upon the variations within the subsurface soil profile, the structural loading conditions, the embedment depth of the footings, the thickness of compacted fill, and the quality of the earthwork operations. The above settlement estimates have assumed that the maximum footing size is 8.0 feet for spread footings and 4.0 feet for strip footings.

[4] The sides of the excavation for foundations must be nearly vertical and the concrete should be placed neat against these vertical faces for the passive earth pressure values to be valid. If the loaded side is sloped or benched, and then backfilled, the allowable passive pressure will be significantly reduced. Passive resistance in the upper 2 feet of the soil profile should be neglected. If passive resistance is used to resist lateral loads, the base friction should be neglected. This allowable passive pressure contains a factor of safety of 2.

[5] The coefficient of sliding friction is given as an ultimate value with no factor of safety included.

Foundations in Areas of Borings B-2 through B-5		
Description	**Individual Footings**	**Strip Foundation**
Net allowable bearing capacity [1] ■ **compacted structural fill**	3,000 psf	
Minimum dimensions	30 inches	24 inches
Minimum embedment below finished grade for frost protection[2]	24 inches	
Approximate total settlement [3]	1 inch	
Approximate differential settlement [3]	¾ inch	
Allowable passive pressure [4]	135 psf triangular distribution	
Ultimate coefficient of sliding friction [4, 5]	0.33	
Modulus of subgrade reaction (K-value) for mat foundation design[6]	N/A	N/A

[1] The recommended net allowable bearing capacity is the pressure in excess of the minimum surrounding overburden pressure at the footing base elevation. Assumes any unsuitable fill or soft soils, if encountered, will be undercut and replaced with engineered fill.

Foundations in Areas of Borings B-2 through B-5		
Description	**Individual Footings**	**Strip Foundation**

[2] For frost protection consideration, an embedment depth of 12 to 18 inches could be used. However we recommend a 24-inch embedment for frost protection to reduce the effects of seasonal moisture variations in the subgrade soils. This value is intended for use in the design of perimeter footing and footings beneath unheated areas.

[3] The foundation settlement will depend upon the variations within the subsurface soil profile, the structural loading conditions, the embedment depth of the footings, the thickness of compacted fill, and the quality of the earthwork operations. The above settlement estimates have assumed that the maximum footing size is 8.0 feet for spread footings and 4.0 feet for strip footings.

[4] The sides of the excavation for foundations must be nearly vertical and the concrete should be placed neat against these vertical faces for the passive earth pressure values to be valid. If the loaded side is sloped or benched, and then backfilled, the allowable passive pressure will be significantly reduced. Passive resistance in the upper 2 feet of the soil profile should be neglected. If passive resistance is used to resist lateral loads, the base friction should be neglected. This allowable passive pressure contains a factor of safety of 2.

[5] The coefficient of sliding friction is given as an ultimate value with no factor of safety included.

Finished grade is defined as the lowest adjacent grade within five feet of the foundation for perimeter (or exterior) footings and finished floor level for interior footings. The allowable foundation bearing pressure applies to dead loads plus design live load conditions. The design bearing pressure may be increased by one-third when considering total loads that include wind or seismic conditions. The weight of the foundation concrete below grade may be neglected in dead load computations.

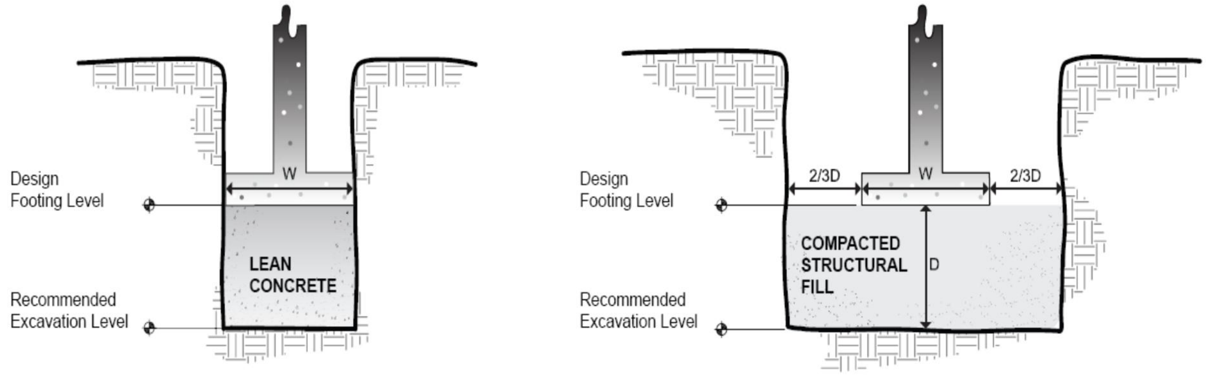
Footings, foundations, and masonry walls (if applicable) should be reinforced as necessary to reduce the potential for distress caused by differential foundation movement. The use of joints at openings or other discontinuities in masonry walls is recommended.

Foundation excavations and engineered fill placement should be observed by a geotechnical engineer of Terracon. If the soil conditions encountered differ significantly from those presented in this report, supplemental recommendations will be required.

4.4.2 Shallow Foundation Construction Considerations

Footing excavations should be protected from standing water or desiccation. The base of all foundation excavations should be free of water and loose soil and rock prior to placing concrete. Excavation of individual footings or sections of continuous footings, placement of steel and concrete, and backfilling should be completed in a reasonably continuous manner. It is preferable that complete installation of individual footings or sections of continuous footings be accomplished in 48 hours.

If the supporting soils in the bottom of the footing become disturbed or unsuitable bearing soils are encountered in footing excavations, the excavations should be extended deeper to suitable soils and the footings could bear directly on these soils at the lower level or on lean concrete backfill placed in the excavations. The footings could also bear on properly compacted backfill extending down to the suitable soils. Over excavation for compacted backfill placement below footings should extend laterally beyond all edges of the footings at least 8 inches per foot of over excavation depth below footing base elevation. The over excavation should then be backfilled up to the footing base elevation with properly compacted fill as described in section **4.2 Earthwork**. The over excavation and backfill procedures are described in the figures below.



Lean Concrete Backfill **Overexcavation / Backfill**

NOTE: Excavations in sketches shown vertical for convenience. Excavations should be sloped as necessary for safety.

Backfilling adjacent and over footings should proceed as soon as practical to reduce disturbance. Backfilling should be accomplished using soils similar to those excavated. All backfill should be uniformly compacted to the criteria presented in Section **4.2.4 Compaction Requirements** of this report. Footing installations should be reviewed by qualified geotechnical personnel to assess the design depth.

4.5 Floor Slab

4.5.1 Floor Slab – Design Recommendations

Item	Description
Floor slab support	Properly prepared subgrade per section **4.2 Earthwork**.
Modulus of subgrade reaction	130 pounds per square inch per inch (psi/inch) for point loading conditions

Slabs-on-grade should be isolated from structures and utilities to allow for their independent movement. Joints should be constructed at regular intervals as recommended by the American Concrete Institute (ACI) to help control the location of any cracking. Keyed and doweled joints should be considered. The owner should be made aware that differential movement between the slabs and foundations could occur if kept structurally independent.

A vapor retarder may be used beneath concrete slabs on grade that will be covered with wood, tile, carpet or other moisture sensitive or impervious coverings, or when the slab will support equipment sensitive to moisture. When conditions warrant the use of a vapor retarder, the slab designer should refer to ACI 302 and/or ACI 360 for procedures and cautions regarding the use and placement of a vapor retarder.

4.5.2 Floor Slab – Construction Considerations

On most project sites, the floor slab subgrades are established early in the construction phase. However as construction proceeds, the subgrade may be disturbed due to utility excavations, construction traffic, desiccation, rainfall, etc. As a result, the floor slab subgrade may not be suitable for placement of concrete and corrective action will be required.

We recommend the floor slab subgrade be rough graded and then thoroughly proof rolled with a loaded tandem axle dump truck according to the recommendations in Section **4.2.1 Site Preparation** prior to fine grading. Particular attention should be paid to high traffic areas that were rutted and disturbed, and to areas where backfilled trenches are located. Areas where unsuitable conditions are found should be repaired by removing and replacing the affected material with properly compacted fill.

4.6 Lateral Earth Pressures

We understand that the raw water storage tanks and sludge drying beds are below grade structures. Recommended lateral earth pressures for below-grade structures are shown in the table below.

We note that lateral earth pressures are a function of soil properties, surcharge loads behind the earth retaining element, and amount of deformation that the soil retention system can undergo. Lateral earth pressures developed from the “active” condition are applicable for design of temporary or permanent free standing retaining walls, if adequate wall movement can occur to fully mobilize the shear strength of the retained soils. Permanent soil retention systems should be designed for pressures utilizing the “at rest” case, however, if soils are moved against the earth retaining element and these soils cause certain inward movement, then the “passive” earth pressure condition will be developed. The earth pressure for different soil movements along the wall cab be calculated according to the below table.

Depth (feet)	Subsurface Material	Equivalent Fluid Pressures		
		Active[2]	At Rest	Passive[1]
0 to 4	Sandy Silty Clay, Sandy Lean Clay or Lean Clay with sand	50 psf/foot – 340 psf (constant)	65 psf/foot	220 psf/foot + 730 psf (constant)

Depth (feet)	Subsurface Material	Equivalent Fluid Pressures		
		Active[2]	At Rest	Passive[1]
4 to 10	Sandy Silty Clay, Sandy Lean Clay or Lean Clay with sand	50 psf/foot – 800 psf (constant)	65 psf/foot	240 (psf/foot) + 1,780 psf (constant)
0 to 10	Caliche	52 psf/foot – 1,620 psf (constant)	74 psf/foot	295 psf/foot + 3,850 psf (constant)

[1] For passive earth pressure conditions, wall movement in a range of 0.005H to 0.01H (H is the height of the wall) is required to fully mobilize passive earth pressures. If this scale of wall movement is not expected, a reduction factor of 50% may be used for passive earth pressure condition design.

[2] In cases where active earth pressures compute as negative values, they should be taken as zero.

We note that the recommended equivalent fluid pressures are based on the parameters shown in the following table.

Depth (feet)	Subsurface Material	Estimated Internal Friction Angle (degrees)	Estimated Cohesion (psf)	Estimated Moist Unit Weight (pcf)
0 to 4	Sandy Silty Clay, Sandy Lean Clay or Lean Clay with sand	21	250	105
4 to 10	Sandy Silty Clay, Sandy Lean Clay or Lean Clay with sand	22	600	110
0 to 10	Caliche	24	1,250	125

The design values listed in the following table were calculated based on the assumption of level backfill, no friction at the wall-soil interface, and no surcharge effects. In addition, the pore water pressure or buoyant unit weight are not invoiced in the above parameters, since groundwater seepage was not encountered during drilling.

A coefficient of friction of 0.31 may be used for calculating the frictional resistance force at the base of the earth retention system. Heavy compaction equipment element is designed for the increased pressure or temporarily braced. Therefore, light compaction equipment may be required in this zone. A permanent drainage system should be considered during earth retaining system design to keep the soil materials behind the walls dry.

4.7 Soil Stiffness

Soil stiffness beneath foundation elements can become problematic under dynamic loading conditions. For this reason, foundation bearing soil stiffness was evaluated based on our geotechnical exploration and laboratory testing. Geotechnical parameters to evaluate overall foundation system stiffness are as follows:

Parameter Description	Value
Design Average Shear Wave Velocity, V_s (feet/s)	1,030
Small Strain Shear Modulus, G_o (ksf)	3,620
Small Strain Elastic Modulus, E_o (ksf)	9,430
Estimated Damping Ratio	0.04
Estimated Poisson's Ratio, μ	0.3

The geotechnical parameters outlined above are based upon correlations between shear wave velocity (V_S) and material types and strengths from depths of approximately 2 feet bgs to the maximum depths of exploration in boring B-4 where the proposed water pumps are located.

4.8 Fault Rupture Review

We reviewed the USGS Earthquake Hazards Program Quaternary Faults and Folds Database available online (https://geohazards.usgs.gov/cfusion/qfault/query_main_AB.cfm). The nearest fault to the project site is the Meers fault (northwestern section (Class A) No. 1031a), which is approximately 165 miles to the east of the project site located in Comanche and Kiowa counties in Oklahoma. According to this source, the fault has been mapped as a strike-slip fault with a sense of movement of left lateral and an average strike of N 67º W and a dip of 80º NE -60º SW. The fault is in the slip rate category of less than 0.2 mm/year.

4.9 Seismic Considerations

Description	Value
Site Classification[1]	D[2]
Approximate Central Site Latitude	34.985518°
Approximate Central Site Longitude	-101.696338°

[1] In general accordance with the *2012 International Building Code,* Section 1613

[2] The 2012 International Building Code (IBC) requires a site soil profile determination extending a depth of 100 feet for seismic site classification. The current scope requested does not include the required 100 foot soil profile determination. The borings were extended to a maximum depth of approximately 16 feet bgs and this seismic site class definition considers that hard caliche materials classified as sandy lean clay (CL) underlay the borings termination depths. Additional exploration to deeper depths would be required to confirm the conditions below the current depth of exploration. Alternatively, a geophysical exploration could be utilized in order to attempt to justify a higher seismic site class.

Spectral acceleration values published by the USGS for the project site location are included in the following table.

Spectral Acceleration	Value
S_S (Spectral Acceleration for a Short Period [0.2 sec])	0.134g
S_1 (Spectral Acceleration for a 1-Second Period)	0.042g
S_{MS} (Spectral Acceleration for a Short Period [0.2 sec])[1]	0.214g
S_{M1} (Spectral Acceleration for a 1-Second Period)[2]	0.102g
S_{DS} (Spectral Acceleration for a Short Period [0.2 sec])[3]	0.143g
S_{D1} (Spectral Acceleration for a 1-Second Period)[4]	0.068g

1	**$S_{MS} = F_a S_S$**
2	**$S_{M1} = F_v S_1$**
3	**$S_{DS} = 2/3 * S_{MS}$**
4	**$S_{D1} = 2/3 * S_{M1}$**
5	**For 2010 ASCE 7 (w/March2013 errata) with risk category of I, II or III** **URL: http://earthquake.usgs.gov/designmaps/us/application.php?**

5.0 GENERAL COMMENTS

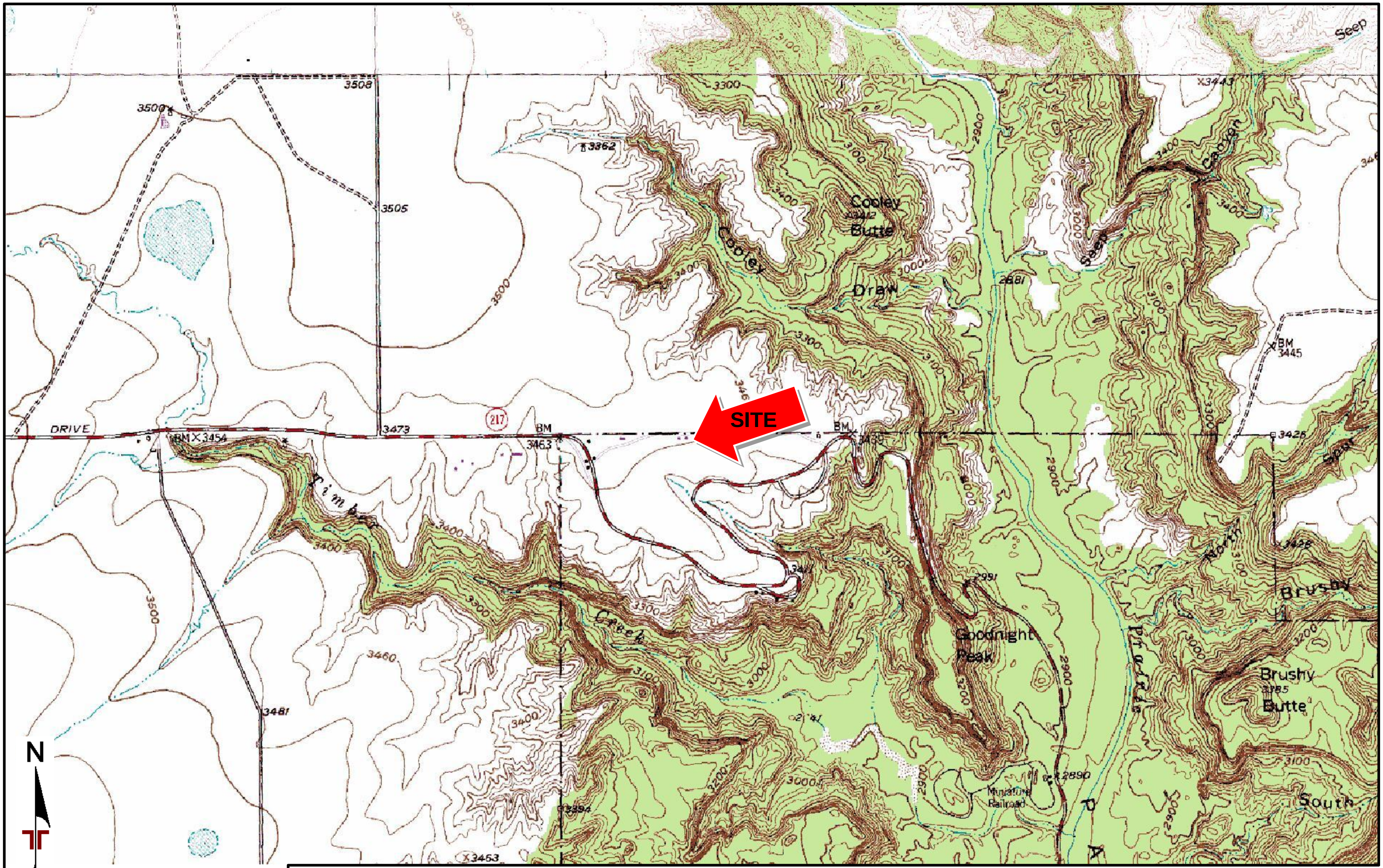
Terracon should be retained to review the final design plans and specifications so comments can be made regarding interpretation and implementation of our geotechnical recommendations in the design and specifications. Terracon also should be retained to provide observation and testing services during grading, excavation, foundation construction and other earth-related construction phases of the project.

The analysis and recommendations presented in this report are based upon the data obtained from the boring performed at the indicated location and from other information discussed in this report. This report does not reflect variations that may occur across the site or due to the modifying effects of weather. The nature and extent of such variations may not become evident until during or after construction. If variations appear, we should be immediately notified so that further evaluation and supplemental recommendations can be provided.

The scope of services for this project does not include either specifically or by implication any environmental or biological (e.g., mold, fungi, bacteria) assessment of the site or identification or prevention of pollutants, hazardous materials or conditions. If the owner is concerned about the potential for such contamination or pollution, other studies should be undertaken.

This report has been prepared for the exclusive use of our client for specific application to the project discussed and has been prepared in accordance with generally accepted geotechnical engineering practices. No warranties, either expressed or implied, are intended or made. Site safety, excavation support, and dewatering requirements are the responsibility of others. In the event that changes in the nature, design, or location of the project as outlined in this report are planned, the conclusions and recommendations contained in this report shall not be considered valid unless Terracon reviews the changes and either verifies or modifies the conclusions of this report in writing.

APPENDIX A
FIELD EXPLORATION



TOPOGRAPHIC MAP IMAGE COURTESY OF THE U.S. GEOLOGICAL SURVEY QUADRANGLES INCLUDE: THOMAS RANCH, TX (1/1/1973) and FORTRESS CLIFF, TX (1/1/1977).

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

Project Manager: Ali Ahmandi	Project No. A4165269
Drawn by: JJD	Scale: 1"=2,000'
Checked by: Jon Sheng	File Name: BLP
Approved by: Jon Sheng	Date: 2/12/2017

Terracon
10400 State Highway 191
Midland, TX 79707-1497

SITE LOCATION PLAN

TPWD - Water Supply Utility Upgrade
NEQ of Palo Duro Drive and Sunday Canyon Road
Palo Duro Canyon State Park, Randall County, Texas

Exhibit
A-1

AERIAL PHOTOGRAPHY PROVIDED BY MICROSOFT BING MAPS

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

Project Manager: Ali Ahmandi	Project No. A4165269
Drawn by: JJD	Scale: AS SHOWN
Checked by: Jon Sheng	File Name: BLP
Approved by: Jon Sheng	Date: 2/12/2017

Terracon

10400 State Highway 191
Midland, TX 79707-1497

SITE EXPLORATION PLAN

TPWD - Water Supply Utility Upgrade
NEQ of Palo Duro Drive and Sunday Canyon Road
Pal Duro Canyon State Park, Randall County, Texas

Exhibit

A-2

Field Exploration Description

Subsurface conditions were explored by drilling six (6) borings at the approximate location indicated on the Boring Location Plan on Exhibit A-2 in this Appendix. The field exploration was performed on January 23, 2017. The test location was established in the field by Terracon's representative by measuring from available reference features and with the use of a handheld GPS device. The boring locations should be considered accurate only to the degree implied by the methods employed to determine them.

The borings were performed using a small size track carrier auger drill. Samples of the soils encountered in the boring were obtained using split-spoon sampling procedures in accordance with standard penetration tests, utilizing an auto-hammer. The samples were tagged for identification, sealed to reduce moisture loss, and taken to the laboratory for further examination, testing, and classification. Following the completion of drilling, the boring was backfilled with soil cuttings.

An automatic SPT hammer was used to advance the split-barrel sampler in the boring performed on this site. A greater efficiency is typically achieved with the automatic hammer compared to the conventional safety hammer operated with a cathead and rope. Published correlations between the SPT values and soil properties are based on the lower efficiency cathead and rope method. This higher efficiency affects the standard penetration resistance blow count (N) value by increasing the penetration per hammer blow over what would be obtained using the cathead and rope method. The effect of the automatic hammer's efficiency has been considered in the interpretation and analysis of the subsurface information for this report.

A field log of the boring was prepared by Terracon's representative. The log included visual classifications of the materials encountered as well as interpretation of the subsurface conditions between samples. The boring log included with this report represent the engineer's interpretation of the field logs and include modifications based on laboratory evaluation of the samples. The boring log is presented on Exhibit A-4 and A-9 in this appendix. General notes to log terms and symbols are presented on Exhibits C-1 and C-2.

BORING LOG NO. B-1

Page 1 of 1

PROJECT: TPWD - Water Supply Utility Upgrade

CLIENT: TPWD
Austin, Texas

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

LOCATION See Exhibit A-2

Latitude: 34.985761° Longitude: -101.696324°

Approximate Surface Elev: 3458 (Ft.) +/-

DEPTH	ELEVATION (Ft.)	Description	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (psf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
		SANDY SILTY CLAY (CL-ML), dark gray, soft			☒	1-1-2 N=3							
		-soft to medium stiff, tan and light brown			☒	2-2-3 N=5				16		25-18-7	50
		-stiff			☒	4-6-7 N=13							
			5										
		-very stiff			☒	12-12-10 N=22							
7.5	3450.5+/-												
		CALICHE; classified as sandy silty clay (CL-ML), light gray and tan, medium dense			☒	13-14-14 N=28				7		21-15-6	46
		-dense	10		☒	21-20-18 N=38							
		-very dense			☒	50/5"							
13.0	3445+/-												
		Boring Terminated Following Auger Refusal at 13 Feet											

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-4

BORING LOG NO. B-2

PROJECT: TPWD - Water Supply Utility Upgrade

CLIENT: TPWD
Austin, Texas

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

LOCATION See Exhibit A-2

Latitude: 34.985645° Longitude: -101.696376°

Approximate Surface Elev: 3457 (Ft.) +/-

GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST			WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS	PERCENT FINES
							TEST TYPE	COMPRESSIVE STRENGTH (psf)	STRAIN (%)			LL-PL-PI	
	SANDY LEAN CLAY (CL), dark brown, medium stiff				☒	2-4-3 N=7							
	1.5	3455.5+/-											
	CALICHE; classified as sandy lean clay (CL), light gray and tan, hard				☒	50/6"							
					☒	14-22-20 N=42							
			5										
					☒	24-22-20 N=42				8		34-14-20	65
	7.0	3450+/-											
	Boring Terminated Following Auger Refusal at 7 Feet												

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-5

BORING LOG NO. B-3

PROJECT: **TPWD - Water Supply Utility Upgrade**

SITE: **NEQ of Palo Duro Dr. & Sunday Canyon Rd.**
Palo Duro Canyon Park, Randall County, TX

CLIENT: **TPWD**
Austin, Texas

LOCATION See Exhibit A-2

Latitude: 34.985581° Longitude: -101.69616°

Approximate Surface Elev: 3454 (Ft.) +/-

GRAPHIC LOG	DEPTH		ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (psf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
▨		**LEAN CLAY WITH SAND (CL)**, dark brown, soft to medium stiff				☒	2-2-3 N=5							
▨		-light gray and tan, stiff				☒	4-6-8 N=14							
▨		-hard				☒	16-18-14 N=32							
▨	5.5		3448.5+/-	5										
▩		**CALICHE; classified as lean clay with sand (CL)**, light gray and tan, hard				☒	24-30-26 N=56				9		36-16-20	71
▩						☒	50/1"							
▩	9.0		3445+/-											
		Boring Terminated Following Auger Refusal at 9 Feet												

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures
See Appendix B for description of laboratory procedures and additional data (if any).
See Appendix C for explanation of symbols and abbreviations.
Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-6

BORING LOG NO. B-4

PROJECT: TPWD - Water Supply Utility Upgrade	**CLIENT: TPWD Austin, Texas**
SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd. Palo Duro Canyon Park, Randall County, TX	

LOCATION See Exhibit A-2

Latitude: 34.985518° Longitude: -101.696338°

Approximate Surface Elev: 3454 (Ft.) +/-

GRAPHIC LOG	DEPTH	DESCRIPTION	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (psf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
▨		**<u>SANDY LEAN CLAY (CL)</u>**, dark brown, medium stiff				☒	3-3-4 N=7							
▨		-very stiff, tan and light gray				☒	8-8-12 N=20							
▨		-hard		5		☒	16-16-17 N=33				10		38-16-22	68
▨						☒	26-20-18 N=38							
▨	9.5		3444.5+/-			☒	18-22-26 N=48							
▩		**<u>CALICHE; classified as sandy lean clay (CL)</u>**, light gray and tan, hard		10		☒	32-23-22 N=45							
▩						☒	27-29-30 N=59				10		38-17-21	58
▩	16.0		3438+/-	15		☒	50/5"							
		Boring Terminated Following Auger Refusal at 16 Feet												

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-7

BORING LOG NO. B-5

Page 1 of 1

PROJECT: TPWD - Water Supply Utility Upgrade

CLIENT: TPWD
Austin, Texas

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

LOCATION See Exhibit A-2

Latitude: 34.985462° Longitude: -101.696487°

Approximate Surface Elev: 3455 (Ft.) +/-

GRAPHIC LOG	DEPTH / ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (psf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
▨	**SANDY LEAN CLAY (CL)**, dark gray, soft to medium stiff			☒	2-2-3 N=5							
▨	-stiff, dark gray and tan			☒	4-6-6 N=12							
▨	-light gray and tan with calcium nodulus			☒	6-6-4 N=10							
▨		5										
▨				☒	6-6-8 N=14							
▨	7.5 3447.5+/-											
☒	**CALICHE; classified as sandy lean clay (CL)**, light gray and tan, hard			☒	50/4"							
☒	9.0 3446+/-											
	Boring Terminated Following Auger Refusal at 9 Feet											

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-8

BORING LOG NO. B-6

Page 1 of 1

PROJECT: TPWD - Water Supply Utility Upgrade

CLIENT: TPWD
Austin, Texas

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

LOCATION See Exhibit A-2

Latitude: 34.985458° Longitude: -101.696612°

Approximate Surface Elev: 3455 (Ft.) +/-

GRAPHIC LOG	DEPTH / ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (psf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
▨	**SANDY LEAN CLAY (CL)**, dark gray, soft to medium stiff			☒	2-3-3 N=6							
▨				☒	3-4-2 N=6							
▨	-tan			☒	3-3-2 N=5				17		34-16-18	58
▨	5.5 3449.5+/-	5										
☒	**CALICHE; classified as sandy lean clay (CL)**, tan, very stiff to hard, with calcium nodulus			☒	12-15-14 N=29							
☒	-hard			☒	50/5"							
☒	9.0 3446+/-											
	Boring Terminated Following Auger Refusal at 9 Feet											

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:

Abandonment Method:
Borings backfilled with soil cuttings upon completion.

See Exhibit A-3 for description of field procedures

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Based on recent Google Earth topographic maps

Notes:

As a result of limitation in site clearing, a lightweight GeoProbe rig was used in this project. All borings were terminated at an auger refusal depth. We note that the termination depths could be deeper if a regular drilling rig (such as, CME 55) could be utilized at this project.

WATER LEVEL OBSERVATIONS

No seepage encountered during drilling

Dry at completion

10400 State Highway 191
Midland, TX

Boring Started: 1/23/2017	Boring Completed: 1/23/2017
Drill Rig: GeoProbe	Driller: Peterson Drilling
Project No.: A4165269	Exhibit: A-9

APPENDIX B
LABORATORY TESTING

Laboratory Testing

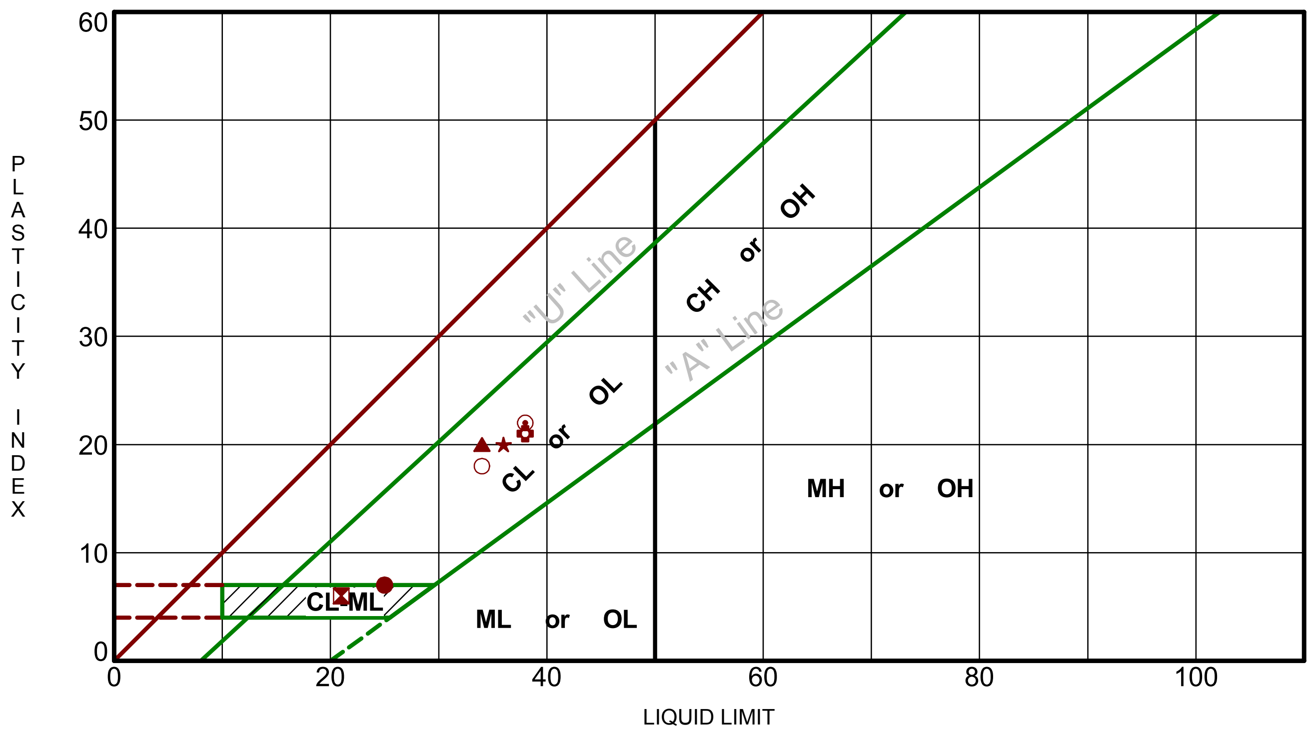
The boring logs and samples were reviewed by a geotechnical engineer who selected soil samples for testing. Tests were performed by technicians working under the direction of the engineer. A brief description of the tests performed follows.

Particle size analysis (ASTM D422), liquid and plastic limit tests (ASTM D4318), and moisture content tests (ASTM D2216) were made to aid in classifying the soils in accordance with the Unified Soil Classification System (USCS). The USCS is summarized on Exhibit C-2 in Appendix C. The results of the laboratory tests are presented on the boring logs in Appendix A. The detailed results of Atterberg limit tests and soil gradation analysis are provided in Appendix B.

Procedural standards noted above are for reference to methodology in general. In some cases variations to methods are applied as a result of local practice or professional judgment.

ATTERBERG LIMITS RESULTS

ASTM D4318



	Boring ID	Depth	LL	PL	PI	Fines	USCS	Description
●	**B-1**	**1.5 - 3**	**25**	**18**	**7**	**50**	**CL-ML**	**SANDY SILTY CLAY**
⧗	**B-1**	**7.5 - 9**	**21**	**15**	**6**	**46**	**SC-SM**	**SILTY, CLAYEY SAND**
▲	**B-2**	**5.5 - 7**	**34**	**14**	**20**	**65**	**CL**	**SANDY LEAN CLAY**
★	**B-3**	**5.5 - 7**	**36**	**16**	**20**	**71**	**CL**	**LEAN CLAY with SAND**
⊙	**B-4**	**3.5 - 5**	**38**	**16**	**22**	**68**	**CL**	**SANDY LEAN CLAY**
✿	**B-4**	**11.5 - 13**	**38**	**17**	**21**	**58**	**CL**	**SANDY LEAN CLAY**
○	**B-6**	**3.5 - 5**	**34**	**16**	**18**	**58**	**CL**	**SANDY LEAN CLAY**

PROJECT: TPWD - Water Supply Utility Upgrade

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

10400 State Highway 191
Midland, TX

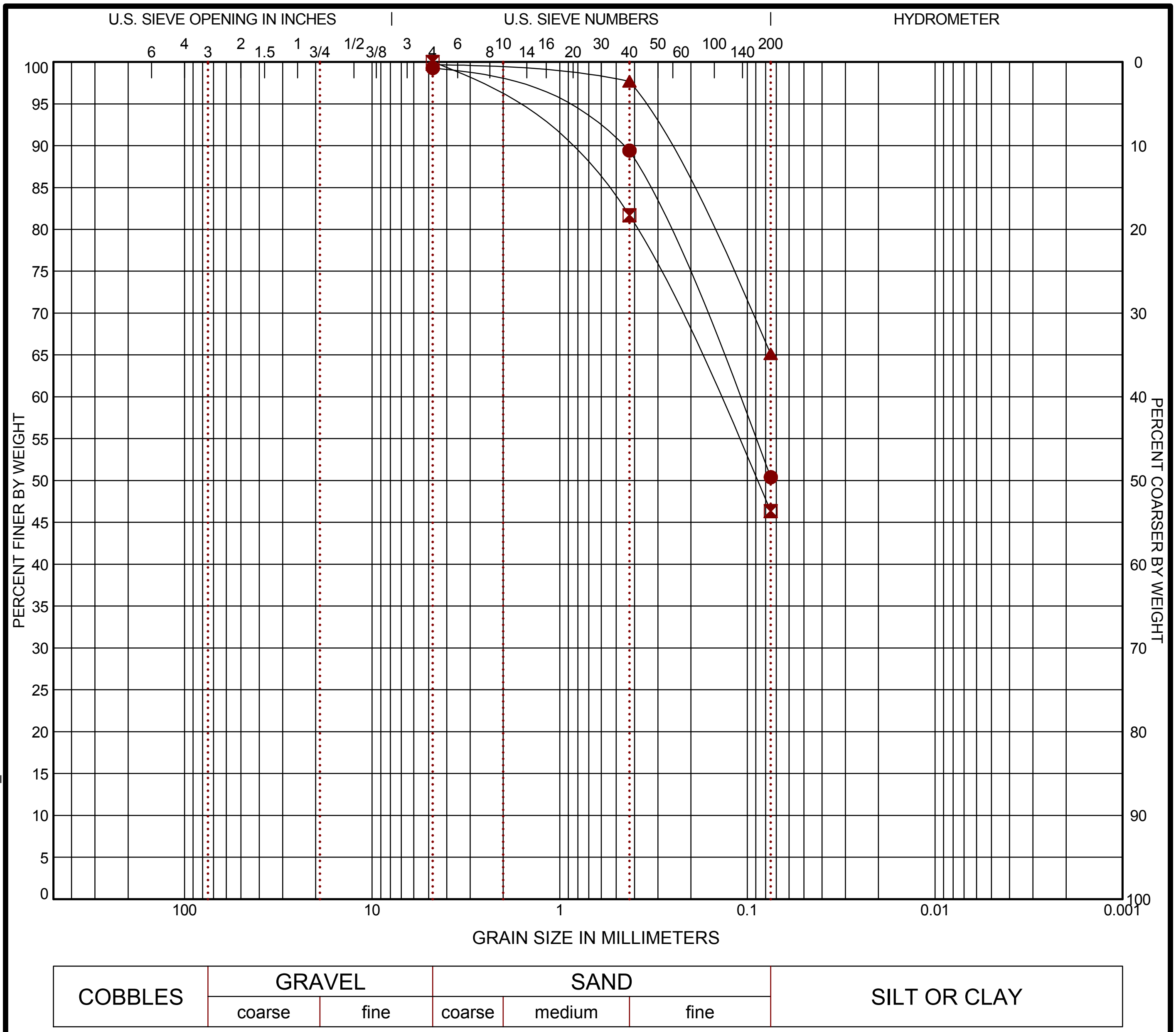
PROJECT NUMBER: A4165269

CLIENT: TPWD
Austin, Texas

EXHIBIT: B-2

GRAIN SIZE DISTRIBUTION

ASTM D422 / ASTM C136



	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**B-1**	**1.5 - 3**			**48.9**		**50.4**		**CL-ML**
☒	**B-1**	**7.5 - 9**	**0.0**	**0.0**	**53.7**		**46.3**		**SC-SM**
▲	**B-2**	**5.5 - 7**			**34.6**		**65.1**		**CL**

	GRAIN SIZE		
	●	☒	▲
D_{60}	**0.115**	**0.147**	
D_{30}			
D_{10}			
	COEFFICIENTS		
C_C			
C_U			

SIEVE (size)	PERCENT FINER		
	●	☒	▲

SOIL DESCRIPTION
- ● SANDY SILTY CLAY (CL-ML)
- ☒ SILTY, CLAYEY SAND (SC-SM)
- ▲ SANDY LEAN CLAY (CL)

REMARKS
- ●
- ☒
- ▲

PROJECT: TPWD - Water Supply Utility Upgrade

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

10400 State Highway 191
Midland, TX

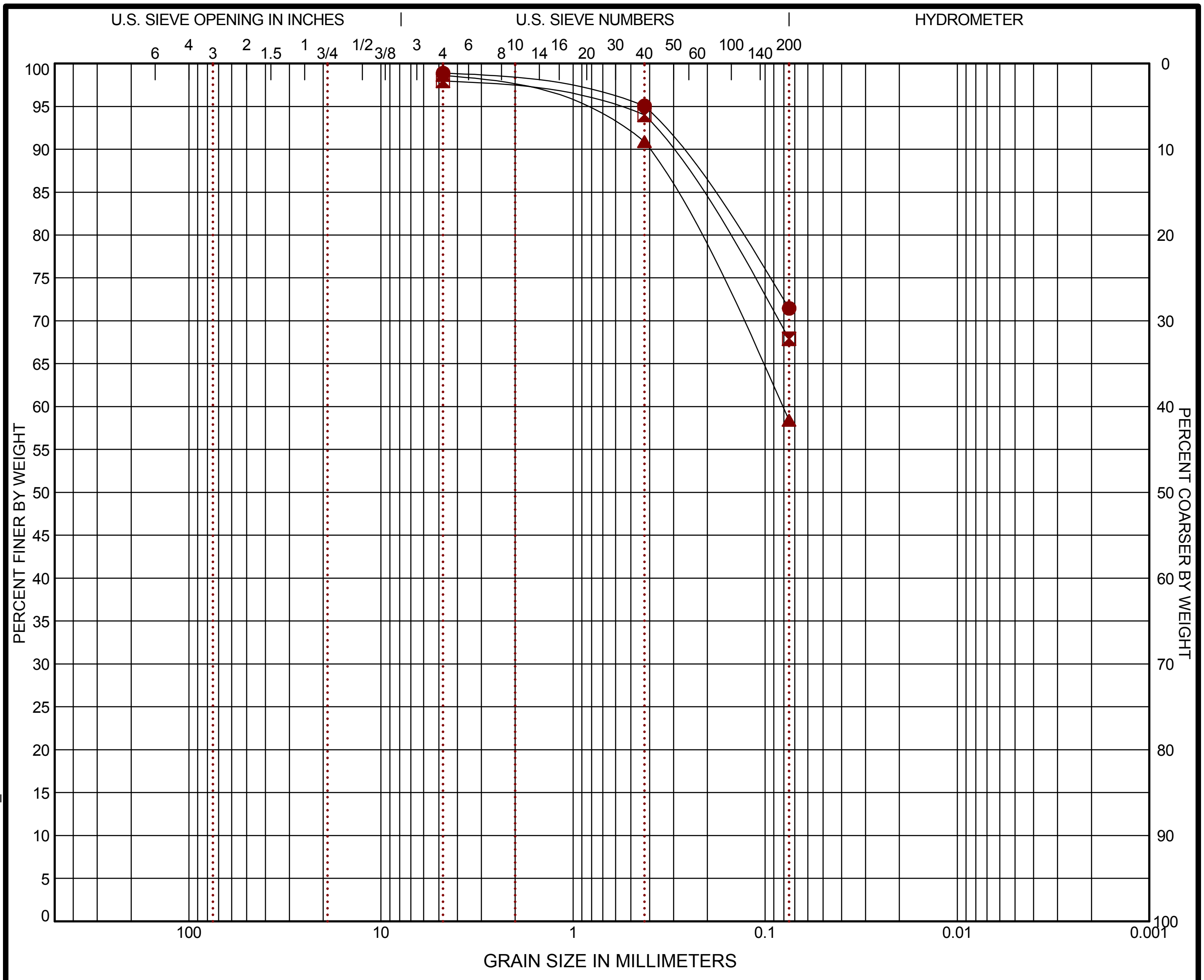
PROJECT NUMBER: A4165269

CLIENT: TPWD
Austin, Texas

EXHIBIT: B-3

GRAIN SIZE DISTRIBUTION

ASTM D422 / ASTM C136



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**B-3**	**5.5 - 7**			**27.4**		**71.5**		**CL**
☒	**B-4**	**3.5 - 5**			**30.1**		**67.9**		**CL**
▲	**B-4**	**11.5 - 13**			**40.2**		**58.4**		**CL**

	GRAIN SIZE		
	●	☒	▲
D_{60}			**0.082**
D_{30}			
D_{10}			
	COEFFICIENTS		
C_C			
C_U			

SIEVE (size)	PERCENT FINER		
	●	☒	▲

SOIL DESCRIPTION

- ● LEAN CLAY with SAND (CL)
- ☒ SANDY LEAN CLAY (CL)
- ▲ SANDY LEAN CLAY (CL)

REMARKS

●

☒

▲

PROJECT: TPWD - Water Supply Utility Upgrade

SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd.
Palo Duro Canyon Park, Randall County, TX

10400 State Highway 191
Midland, TX

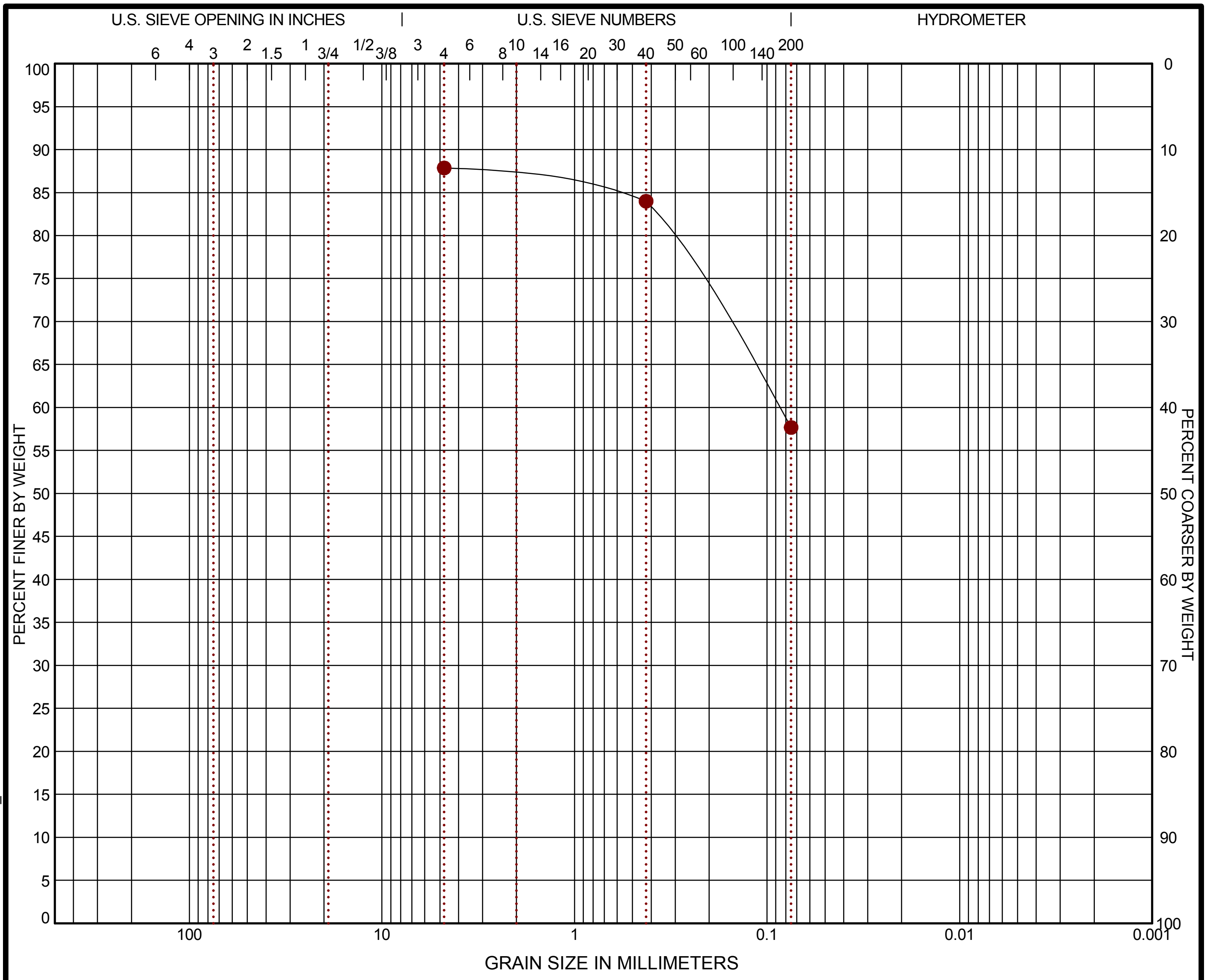
PROJECT NUMBER: A4165269

CLIENT: TPWD
Austin, Texas

EXHIBIT: B-4

GRAIN SIZE DISTRIBUTION

ASTM D422 / ASTM C136



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	BORING ID	DEPTH	% COBBLES	% GRAVEL	% SAND	% SILT	% FINES	% CLAY	USCS
●	**B-6**	**3.5 - 5**			**30.2**		**57.7**		

	GRAIN SIZE		
	●		
D_{60}	**0.087**		
D_{30}			
D_{10}			
	COEFFICIENTS		
C_C			
C_U			

SIEVE (size)	PERCENT FINER		
	●		

SOIL DESCRIPTION
●

REMARKS
●

PROJECT: TPWD - Water Supply Utility Upgrade		PROJECT NUMBER: A4165269
SITE: NEQ of Palo Duro Dr. & Sunday Canyon Rd. Palo Duro Canyon Park, Randall County, TX	10400 State Highway 191 Midland, TX	CLIENT: TPWD Austin, Texas
		EXHIBIT: B-5

LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GRAIN SIZE: USCS 1 A4165269.GPJ TERRACON_DATATEMPLATE.GDT 2/12/17

APPENDIX C
SUPPORTING DOCUMENTS

GENERAL NOTES

DESCRIPTION OF SYMBOLS AND ABBREVIATIONS

SAMPLING

☒	Split Spoon

WATER LEVEL

▽	**Water Initially Encountered**
▽	**Water Level After a Specified Period of Time**
▼	**Water Level After a Specified Period of Time**

Water levels indicated on the soil boring logs are the levels measured in the borehole at the times indicated. Groundwater level variations will occur over time. In low permeability soils, accurate determination of groundwater levels is not possible with short term water level observations.

FIELD TESTS

N	**Standard Penetration Test Resistance (Blows/Ft.)**
(TC)	**TxDOT Cone Penetration Test (blows per Foot)**
(HP)	**Hand Penetrometer**
(T)	**Torvane**
(DCP)	**Dynamic Cone Penetrometer**
(PID)	**Photo-Ionization Detector**
(OVA)	**Organic Vapor Analyzer**

DESCRIPTIVE SOIL CLASSIFICATION

Soil classification is based on the Unified Soil Classification System. Coarse Grained Soils have more than 50% of their dry weight retained on a #200 sieve; their principal descriptors are: boulders, cobbles, gravel or sand. Fine Grained Soils have less than 50% of their dry weight retained on a #200 sieve; they are principally described as clays if they are plastic, and silts if they are slightly plastic or non-plastic. Major constituents may be added as modifiers and minor constituents may be added according to the relative proportions based on grain size. In addition to gradation, coarse-grained soils are defined on the basis of their in-place relative density and fine-grained soils on the basis of their consistency.

LOCATION AND ELEVATION NOTES

Unless otherwise noted, Latitude and Longitude are approximately determined using a hand-held GPS device. The accuracy of such devices is variable. Surface elevation data annotated with +/- indicates that no actual topographical survey was conducted to confirm the surface elevation. Instead, the surface elevation was approximately determined from topographic maps of the area.

STRENGTH TERMS

RELATIVE DENSITY OF COARSE-GRAINED SOILS (More than 50% retained on No. 200 sieve.) Density determined by Standard Penetration Resistance		**CONSISTENCY OF FINE-GRAINED SOILS** (50% or more passing the No. 200 sieve.) Consistency determined by laboratory shear strength testing, field visual-manual procedures or standard penetration resistance		
Descriptive Term (Density)	**Standard Penetration or N-Value Blows/Ft.**	**Descriptive Term (Consistency)**	**Unconfined Compressive Strength Qu, (psf)**	**Standard Penetration or N-Value Blows/Ft.**
Very Loose	0 - 3	Very Soft	less than 500	0 - 1
Loose	4 - 9	Soft	500 to 1,000	2 - 4
Medium Dense	10 - 29	Medium Stiff	1,000 to 2,000	4 - 8
Dense	30 - 50	Stiff	2,000 to 4,000	8 - 15
Very Dense	> 50	Very Stiff	4,000 to 8,000	15 - 30
		Hard	> 8,000	> 30

RELATIVE PROPORTIONS OF SAND AND GRAVEL

Descriptive Term(s) of other constituents	Percent of Dry Weight
Trace	< 15
With	15 - 29
Modifier	> 30

GRAIN SIZE TERMINOLOGY

Major Component of Sample	Particle Size
Boulders	Over 12 in. (300 mm)
Cobbles	12 in. to 3 in. (300mm to 75mm)
Gravel	3 in. to #4 sieve (75mm to 4.75 mm)
Sand	#4 to #200 sieve (4.75mm to 0.075mm
Silt or Clay	Passing #200 sieve (0.075mm)

RELATIVE PROPORTIONS OF FINES

Descriptive Term(s) of other constituents	Percent of Dry Weight
Trace	< 5
With	5 - 12
Modifier	> 12

PLASTICITY DESCRIPTION

Term	Plasticity Index
Non-plastic	0
Low	1 - 10
Medium	11 - 30
High	> 30

Terracon

Exhibit: C-1

UNIFIED SOIL CLASSIFICATION SYSTEM

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests [A]					Soil Classification	
					Group Symbol	**Group Name** [B]
Coarse Grained Soils: More than 50% retained on No. 200 sieve	**Gravels:** More than 50% of coarse fraction retained on No. 4 sieve	**Clean Gravels:** Less than 5% fines [C]	$Cu \geq 4$ and $1 \leq Cc \leq 3$ [E]		GW	Well-graded gravel [F]
			$Cu < 4$ and/or $1 > Cc > 3$ [E]		GP	Poorly graded gravel [F]
		Gravels with Fines: More than 12% fines [C]	Fines classify as ML or MH		GM	Silty gravel [F,G,H]
			Fines classify as CL or CH		GC	Clayey gravel [F,G,H]
	Sands: 50% or more of coarse fraction passes No. 4 sieve	**Clean Sands:** Less than 5% fines [D]	$Cu \geq 6$ and $1 \leq Cc \leq 3$ [E]		SW	Well-graded sand [I]
			$Cu < 6$ and/or $1 > Cc > 3$ [E]		SP	Poorly graded sand [I]
		Sands with Fines: More than 12% fines [D]	Fines classify as ML or MH		SM	Silty sand [G,H,I]
			Fines classify as CL or CH		SC	Clayey sand [G,H,I]
Fine-Grained Soils: 50% or more passes the No. 200 sieve	**Silts and Clays:** Liquid limit less than 50	**Inorganic:**	$PI > 7$ and plots on or above "A" line [J]		CL	Lean clay [K,L,M]
			$PI < 4$ or plots below "A" line [J]		ML	Silt [K,L,M]
		Organic:	Liquid limit - oven dried	< 0.75	OL	Organic clay [K,L,M,N]
			Liquid limit - not dried			Organic silt [K,L,M,O]
	Silts and Clays: Liquid limit 50 or more	**Inorganic:**	PI plots on or above "A" line		CH	Fat clay [K,L,M]
			PI plots below "A" line		MH	Elastic Silt [K,L,M]
		Organic:	Liquid limit - oven dried	< 0.75	OH	Organic clay [K,L,M,P]
			Liquid limit - not dried			Organic silt [K,L,M,Q]
Highly organic soils:	Primarily organic matter, dark in color, and organic odor				PT	Peat

[A] Based on the material passing the 3-inch (75-mm) sieve

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12% fines require dual symbols: GW-GM well-graded gravel with silt, GW-GC well-graded gravel with clay, GP-GM poorly graded gravel with silt, GP-GC poorly graded gravel with clay.

[D] Sands with 5 to 12% fines require dual symbols: SW-SM well-graded sand with silt, SW-SC well-graded sand with clay, SP-SM poorly graded sand with silt, SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $\quad Cc = \dfrac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ≥ 15% sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains ≥ 15% gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in shaded area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29% plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains ≥ 30% plus No. 200 predominantly sand, add "sandy" to group name.

[M] If soil contains ≥ 30% plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] $PI \geq 4$ and plots on or above "A" line.

[O] $PI < 4$ or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.

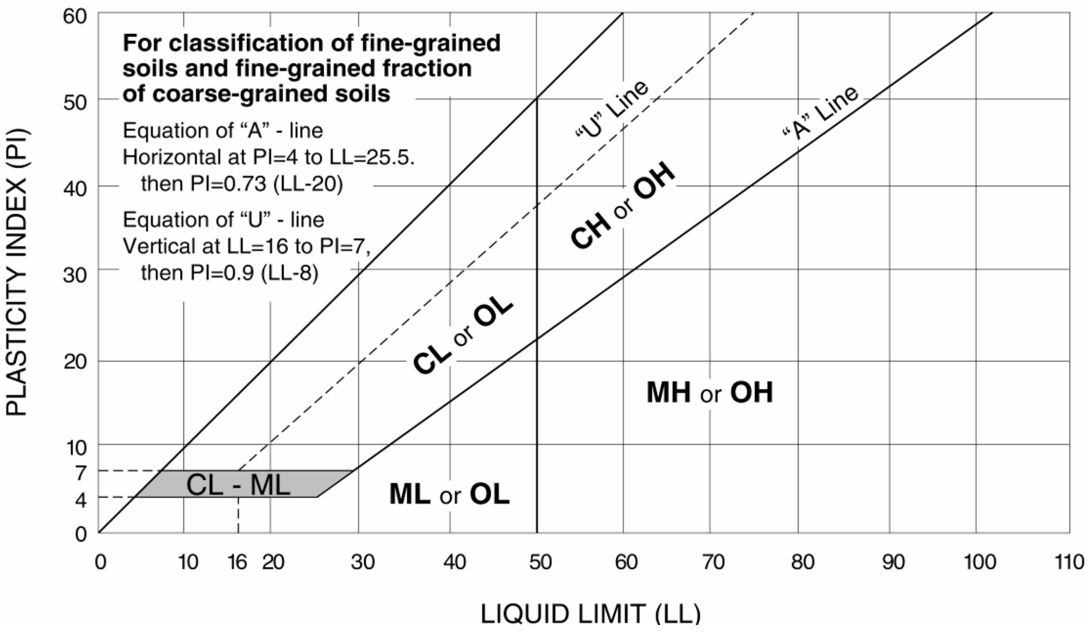


Exhibit C-2